COMPATIBILITY OF UNITED STATES RADIOSONDES

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ABSTRACT

Comparative data are reported from a group of twin or dual radiosonde observations made with U.S. Weather Bureau and military 1680-mc./sec. radiosondes. To compare the instruments directly, differences in temperature, pressure, and relative humidity are studied at simultaneous time marks during the observations. Root-mean-square differences of pressure, temperature, and relative humidity for each observation are summarized in table form. The root-mean-square differences for all observations combined are 2.1 mb. and 0.51° C.

Tables show temperature and height differences evaluated at constant pressure surfaces. These temperature differences are somewhat greater than those at simultaneous time marks, as would be expected with the permitted tolerances and the judgment required in placing levels. Moreover, temperature differences obtained by this method are modified by pressure differences.

Both types of radiosondes give compatible measurements, at least to the levels reached.

The radiosondes were obtained from field stock, were not changed or adjusted in the laboratory, and were flown in the same manner as for routine soundings except for the dual feature. Certain laboratory tests were conducted and factory calibration data were obtained from these radiosondes. These tests and data are reported but were not used in the evaluations of the observations.

1. INTRODUCTION

Unexplained and often large differences in radiosonde data observed by adjacent stations caused considerable skepticism, especially in earlier years, concerning the accuracy of the data. Accuracy and compatibility of United States radiosondes are now much improved. Internationally, discrepancies may exist where different types are used by neighboring countries. The World Meteorological Organization (WMO) [2] has been cognizant of this, and international comparisons of radiosondes have been made in an effort to determine systematic differences in the hope that by applying statistical corrections all data could be reduced to a uniform scale. The existence of differences was confirmed by those comparisons, but meaningful corrections could not be derived from them.

In the United States, field programs of dual and multiple soundings are conducted from time to time to determine variability of performance between different types of radiosondes. For example, interagency tests were made at Oklahoma City in 1951 [1], and continued field tests have been performed by the Instrumental Engineering Division of the U.S. Weather Bureau over the years. Little has been published of the latter tests as their primary purpose was to confirm laboratory tests and to serve as a supplementary method for quality control.

The tests described here were to determine compatibility between radiosondes of a similar type that differ in construction and manufacturers. These tests were on a broader scale and more detailed than other routine tests. They also comply with the WMO [2] recommendation for members to make twin soundings and to publish the results.

The radiosondes in use by United States meteorological agencies are manufactured by methods requiring mass production techniques both in assembly and in calibration. These techniques allow for manufacturing tolerances which permit small bandwidth departures from the true measured values at standard calibration points. These departures may show up as differences between instruments used for synoptic observations, particularly between instruments produced by different manufacturers or during contracts for different years or, for that matter, between different production lots from the same manufacturer. For discussions of manufacturing tolerances and expected sources and magnitudes of errors the reader is referred to [1] and [3].

The data reported here were obtained in a small-scale compatibility test conducted in September 1960 by the Instrumental Engineering Division in cooperation with Observations and Station Facilities Division (now Data Acquisition Division) of the U.S. Weather Bureau. The purpose was to determine if systematic differences existed between current Weather Bureau and military radiosondes and if the degree of scatter or random variation in a small sample was within the limits to be expected from the manufacturing tolerances. Each observation was made with a balloon train carrying two radiosondes, one Weather Bureau 1680 mc./sec. and one military AN/
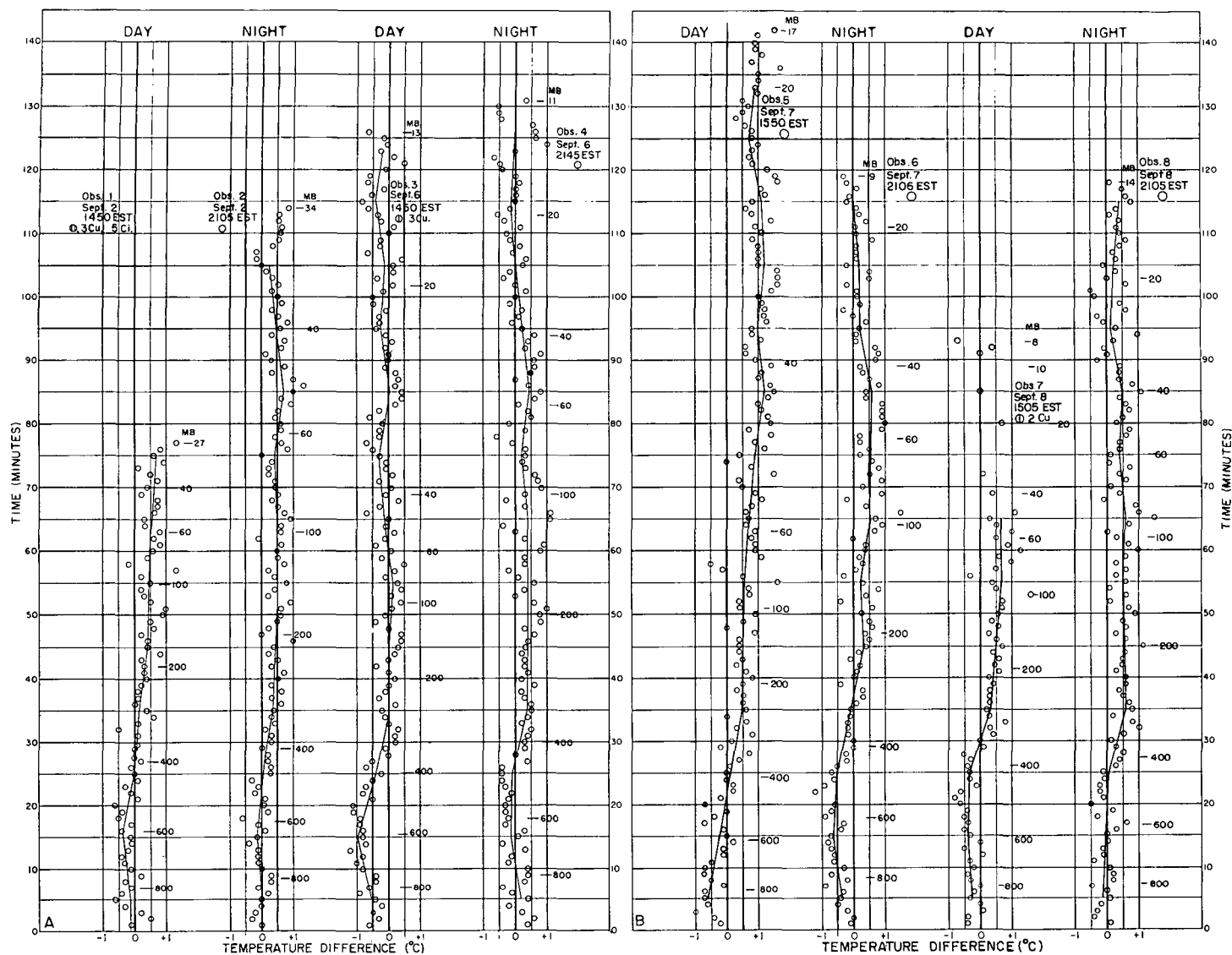
FIGURE 1.—Temperature differences between pairs of radiosondes, Weather Bureau radiosonde observation minus military radiosonde observation, at simultaneous time signals 1 min. apart.

AMT–4B. The balloon train was arranged so that the minimum distance between the balloon and the top radiosonde was 45 ft.; the maximum distance was 70 ft. The minimum distance between the parachute and the top radiosonde was 25 ft.; the maximum distance was 50 ft. The distance between the top and bottom radiosondes was always 25 ft. A sling was provided so that the load of the bottom radiosonde was carried by the cord, not by the top radiosonde.

Two successive observations were released within approximately a 12-hr. period, one daytime and one nighttime, usually early evening. The position of each radiosonde on the balloon train was interchanged at each daytime observation. The instruments used in this experiment were obtained from stocks for field issue and were representative of radiosondes current at that time. They were not changed or otherwise adjusted in the labora-

tory and were flown in the field in the same manner as routine soundings, except for the dual feature. To obtain the maximum amount of information, some laboratory measurements (to be described later) were conducted on the radiosondes. These measurements had no effect on performance since no changes or adjustments were made to the radiosondes.

The Weather Bureau radiosondes were from the 1960 fiscal year procurement, date of manufacture June 1960, all from one manufacturer. Some of the military radiosondes were manufactured in 1955, some in 1958, by two different manufacturers, and both different from the manufacturer of the Weather Bureau instruments. All radiosondes had the white-coated thermistor, exposed on an outrigger. The thermistor on the Weather Bureau radiosonde was about 0.045 in. in diameter. It was 4½ in. from the nearest point on the box and above the box at

FIGURE 1.—Continued.
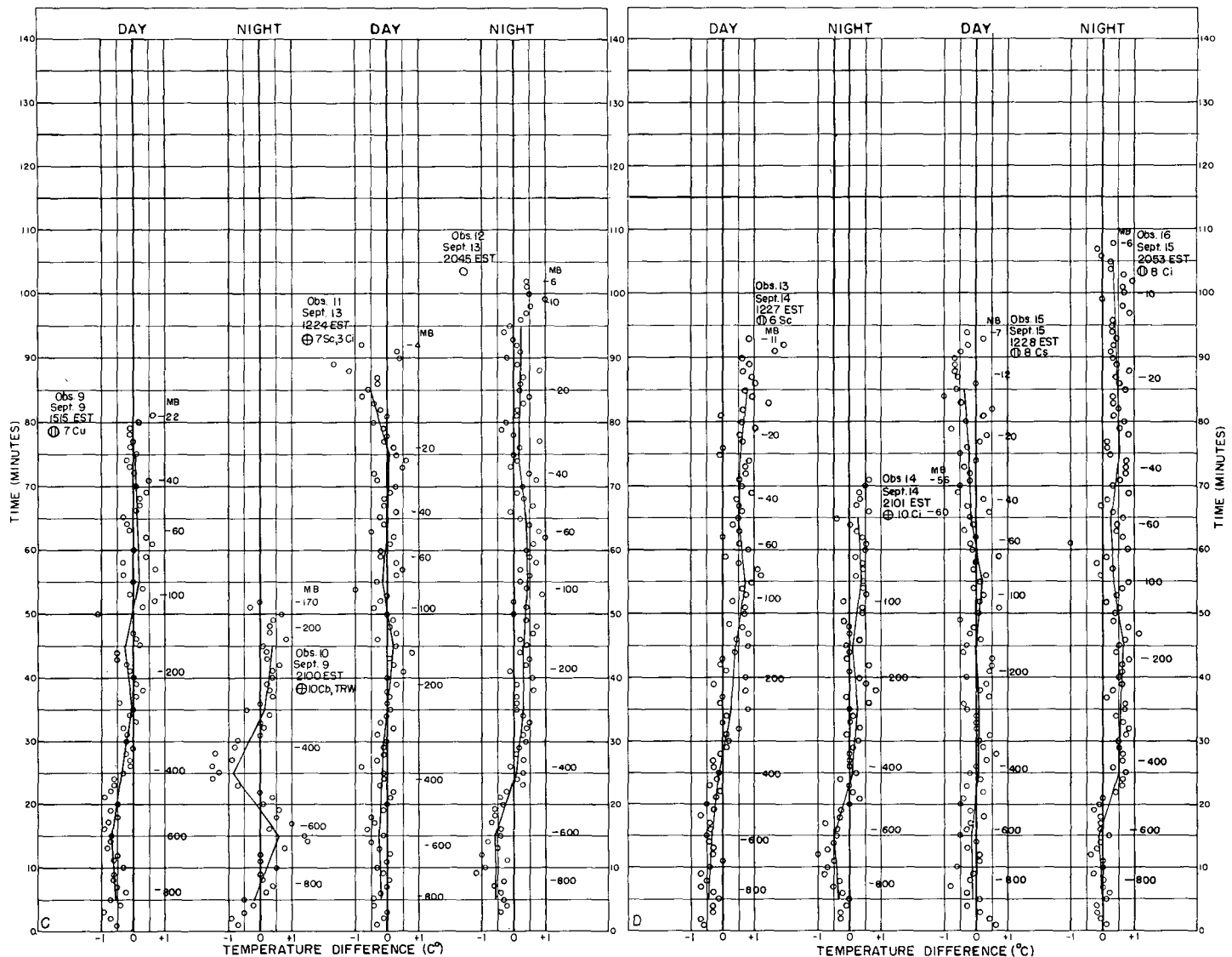
an angle of about 45° to the top surface. The thermistor on the military radiosonde was about 0.035 in. in diameter. It was 3½ in. from the nearest point on the box and only slightly above the top, making an angle of about 20° with the horizontal at the nearest top edge. For measuring relative humidity, lithium chloride elements were used on the Weather Bureau instruments and carbon elements (CML–476/AMT–4) on the military instruments.

Meteorological technicians at the Weather Bureau's Observational Test and Development Center assisted in the baseline checks and in launching the train. They also carried out evaluations for all the soundings. A total of 16 pairs of observations was made, 8 pairs by day and 8 by night. Since the primary purpose of the tests was to make comparisons of simultaneous indications, a timer produced simultaneous marks at 1-min. intervals on the recordings of the two sets of ground equipment. Pressure, temperature, and relative-humidity readings were made at these simultaneous marks at 1-min. intervals. In addition, the soundings were evaluated for data at significant points and at standard pressure levels using operational procedures described in [4].

A study of this nature gives relative numbers only and no conclusion can be drawn as to the accuracy of either radiosonde. Information of relative accuracy may be obtained from laboratory data and from correlation of observational or flight data with laboratory data. The sampling of radiosondes used in this study is too small for statistically sound conclusions as to accuracy.

2. COMPARISON AT SIMULTANEOUS TIMES

To compare the instruments directly, the instantaneous readings of temperature, pressure, and relative humidity obtained on both radiosonde records at simultaneous time signals 1 min. apart were evaluated, and differences between them were determined for radiosonde pairs.

Figures 1 and 4 show temperature and pressure differences for each pair in the chronological order of the observations. Because of the time-sharing nature of the sensors, interpolation between temperature segments (or humidity segments) is usually necessary on one or both radiosonde records.

The point show differences (Weather Bureau radiosonde value minus military radiosonde value) for temperature or pressure, as a function of a linear time scale. Pressure values of the Weather Bureau radiosonde corresponding to the ascent time scale are shown for each observation. The solid lines of figures 1 and 4 connect successive 10-min. averages of the individual points. For example, on observation 1, figure 1(A), the average value for minutes 1 to 10, inclusive, (−0.1° C.) is plotted at minute 5; the average value for minutes 11 to 20 (−0.3° C.) is plotted at minute 15. These points are connected by a straight line. The line is intended only as an aid to judging systematic differences, if any exist, between the pairs of radiosondes and has no effect on results of the study.

Figure 1 shows the differences in temperature measurement between the two radiosondes. These differences vary from observation to observation and even within an observation. The most outstanding feature is the bandwidth of the non-systematic or random scatter which, in general, is about 1° and is slightly more in the upper levels than in the lower levels. This scatter of the data is caused primarily by the resolution of the ground equipment and evaluators (see [3]), and by interpolations. Figure 2 demonstrates the contribution to the scatter from these sources of error only. This shows differences in evaluated temperatures when a single radiosonde observation is recorded on two sets of ground equipment and each is evaluated as though from independent observations. The bandwidth of the scatter is comparable to that for the differences between pairs of radiosondes, implying that the major portion of the scatter originates from sources other than the radiosonde itself.

The scatter in the data for the upper levels is somewhat larger than for the lower levels. This results from the larger number of temperature interpolations necessary in upper levels and the greater error in temperature resulting from interpolation. In the lower levels interpolations were over short time intervals and small errors resulted except for an occasional instance during a rapid rate of change of the variable. In the upper levels of the observation, however, temperature and reference segments were several minutes long. As a consequence, the time marks seldom occurred when both radiosondes were transmitting temperature data. Thus temperatures were interpolated for one or both radiosondes for the majority of the time marks. In this comparison the number of temperature interpolations was greatly increased at pressures less than 150 mb. for the military radiosonde because of the unusually long reference segment and short temperature segment.
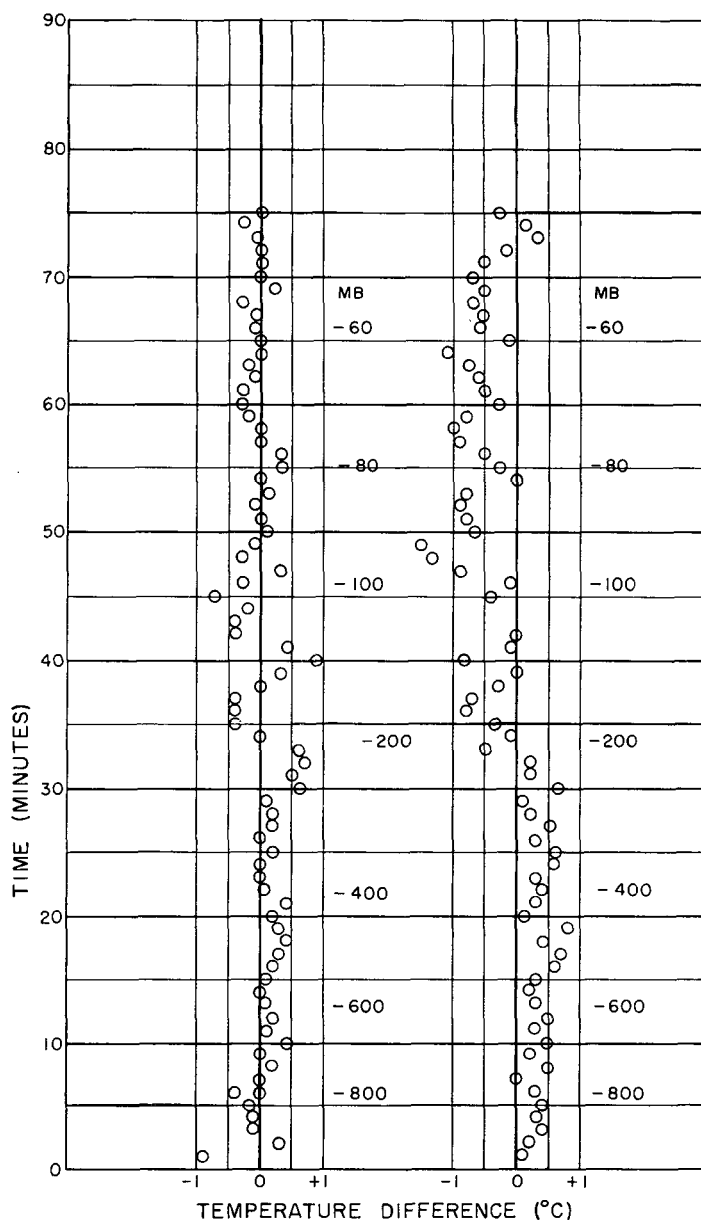

FIGURE 2.—Two examples of the indicated temperature differences of a radiosonde observation recorded on two sets of ground equipment and evaluated as independent observations.

The small systematic difference in temperature between the two groups of radiosondes is almost lost in the scatter and in the individual difference trends between pairs. This observed difference is shown in the statistical distribution curves of figure 3, and again in figure 7 where it is compared with expected calibration differences. The following percentages of differences falling within the designated intervals were computed from the total distribution curve (curve C, fig. 3).

70.4 percent within 0.0° C. to ± 0.5° C.
95.9 percent within 0.0° C. to ± 1.0° C.
99.4 percent within 0.0° C. to ± 1.5° C.
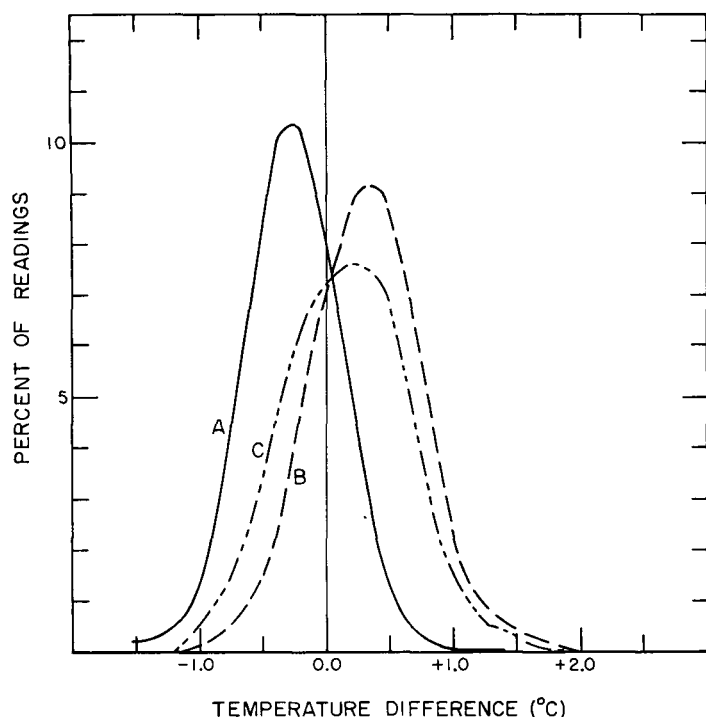Maximum difference (1 point only) 1.9° C.

FIGURE 3.—Averaged distribution curves of temperature differences at simultaneous times: (A) surface to 400 mb.: (B) pressure less than 400 mb.; (C) all points.

TABLE 1.—*Summary of radiosonde comparisons at simultaneous times giving the root-mean-square of pressure differences ($\sigma_{\Delta p}$), of temperature differences ($\sigma_{\Delta T}$), and of relative humidity differences ($\alpha_{\Delta H}$) for each pair of radiosondes*

Date Sept. 1960	Time (EST)	Flight No.	Day or night	Height (mb.)	$\sigma_{\Delta p}$ (mb.)	$\sigma_{\Delta T}$ (° C.)	$\sigma_{\Delta H}$ (percent)
2	1450	1	D	27	1.9	0.48	9
2	2105	2	N	34	2.8	.48	11
6	1451	3	D	13	2.3	.44	12
6	2145	4	N	11	1.1	.44	8
7	1515	5	D	17	1.4	.87	9
7	2106	6	N	18	1.1	.50	9
8	1505	7	D	8	2.5	.53	6
8	2105	8	N	14	1.2	.50	13
9	1515	9	D	22	3.0	.44	7
9	2100	10	N	174	3.2	.66	29
13	1224	11	D	4	3.1	.39	6
13	2045	12	N	6	1.6	.45	4
14	1227	13	D	11	1.7	.62	3
14	2101	14	N	56	3.1	.39	2
15	1228	15	D	7	1.8	.38	5
15	2053	16	N	6	1.7	.48	4

Curve A, figure 3, shows the distribution of temperature differences for points from the surface to 400 mb., and curve B, for points with pressure less than 400 mb. In the lower levels, the temperatures obtained by the Weather Bureau radiosonde were 0.2° C. to 0.3° C. lower than those obtained by the military radiosonde; but in the upper levels the trend was reversed—the temperatures of the Weather Bureau radiosonde were higher by about 0.4° C. Many of the large differences, particularly at the upper levels, shown in figures 1 and 3, resulted from interpolation when a time mark fell between temperature segments. In addition, a few large differences may be attributed to peculiar temperature behavior of the top radiosonde after one balloon of a two-balloon train burst. These large differences are peculiar to this type of experiment.

One point, although difficult to explain, seems worthy of mention. The indicated temperatures of the Weather Bureau radiosonde are lower than the military by several tenths of a degree for various levels above the surface, sometimes extending to 500 mb. depending upon the observation. Inspection of the records and adiabatic charts indicates a relation with cloud occurrence, particularly with low-level cumulus-type clouds. (See weather and cloud conditions for each observation, fig. 1.) In one case, observation No. 10, the temperature obtained by the military radiosonde was higher than that obtained by the weather Bureau radiosonde within a thunderstorm cloud. This condition is typical of a wet radiosonde, a conclusion based on laboratory studies and routine specification tests.

It implies electrical leakage of the military radiosonde as a result of moisture shunting some vulnerable component in the temperature circuit.

The pressure differences at simultaneous times are shown for the individual observations in figure 4 and as composite distribution curves in figure 5. As would be expected from the design characteristics of the baroswitch, the maximum scatter and largest differences occur at high pressure values. The pressure scale sensitivity near 20 mb. is about four times that near 1000 mb. This increased sensitivity for low pressures results both in smaller absolute errors and in less scatter, as is shown by a comparison of curve A with B of figure 5. Pressures from the Weather Bureau radiosonde are 1 to 1.5 mb. lower on the average than those from the military instrument. This may result from calibration errors, temperature compensation errors, or errors arising from the surface pressure setting of either or both radiosondes.

For pressures from the surface to 400 mb., 89 percent of all the differences were within ±4 mb., the maximum difference (7 mb.) occurring twice. For pressures less than 400 mb., 95 percent were within ±3 mb., the maximum difference (5 mb.) occurring five times.

Since the relative humidity sensors, one lithium chloride and one carbon, have different characteristics and response rates, little can be learned from a presentation of differences in relative humidity measurements. Differences were obtained for use in table 1 and 79 percent fall within the bandwidth of ± 10 percent.

Table 1 shows a summary of the individual observations: date; time of release; day or night; minimum pressure of usable data; and the root-mean-square differences of pressure, temperature, and relative humidity evaluated at simultaneous times for each pair of radiosondes.

For pressure, the root-mean-square differences range from 1.1 mb. to 3.1 mb., and for temperature, from 0.38° C. to 0.87° C. The root-mean-square differences for all the observations combined are 2.1 mb. and 0.51° C.; by day, 2.2 mb. and 0.52° C.; and by night, 2.2 mb. and 0.49° C.
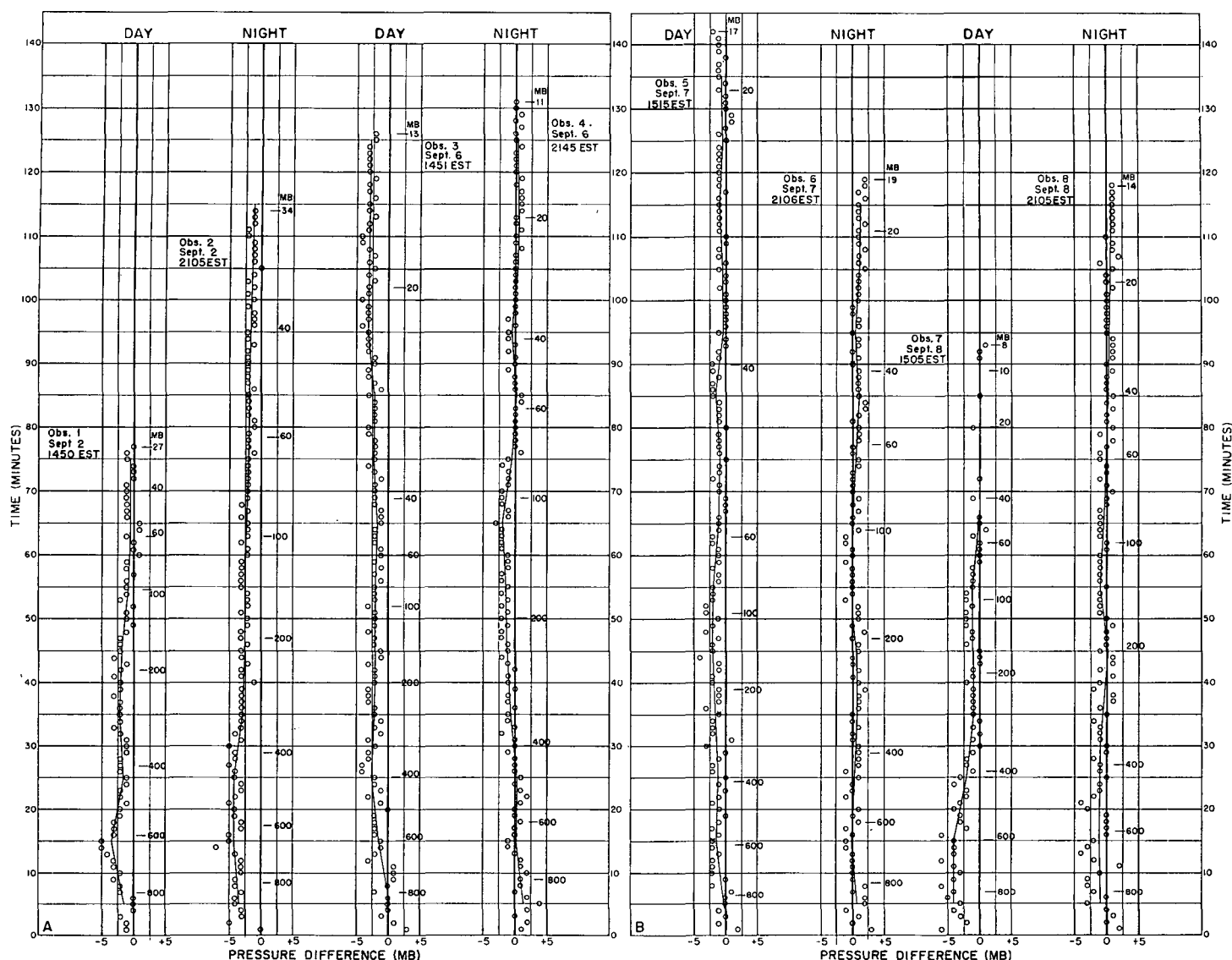
FIGURE 4.—Pressure differences between pairs of radiosondes, Weather Bureau radiosonde observation minus military radiosonde observation, at simultaneous time signals 1 min. apart.

An estimate of the standard deviation in temperature of 0.36° C. for one radiosonde was obtained [3] by using the maximum permissible errors from the specifications, and by assigning corresponding maximum errors to ground equipment and to data evaluation. Assuming that temperature errors are independent and normally distributed, 68.3 percent of the errors (or departure of indicated temperature from the true) should fall within the bandwidth ±0.36° C., 95.5 percent should fall within ±0.72° C., and 99.7 percent should fall within ±1.1° C.

If two radiosondes are compared to each other, assuming they have the same error distribution, these values become ± 0.50° C. for 68.3 percent, ± 1.0° C. for 95.5 percent, and ± 1.5° C. for 99.7 percent. Observed values from these tests are ± 0.51° C. for 68.3 percent, ± 1.0° C. for 95.9 percent and ± 1.5° C. for 99.4 percent. Since

the baroswitches in the two types of radiosondes can be described as identical, the root-mean-square difference between them of 2.2 mb. is equally contributed by each radiosonde, making the root-mean-square error for one radiosonde about 1.5 mb. Because of the nonlinear behavior of the element, the errors are greater at high pressure and smaller at the lower pressures. These differences do not indicate the accuracy of either group of radiosondes, only their performance relative to each other.

3. COMPARISON OF SYNOPTIC DATA

It was the primary purpose of this study to compare the two groups of radiosondes from the point of view of instrument performance. This is best shown by the simultaneous time evaluations of the previous section. However, to give users of the data the most familiar and
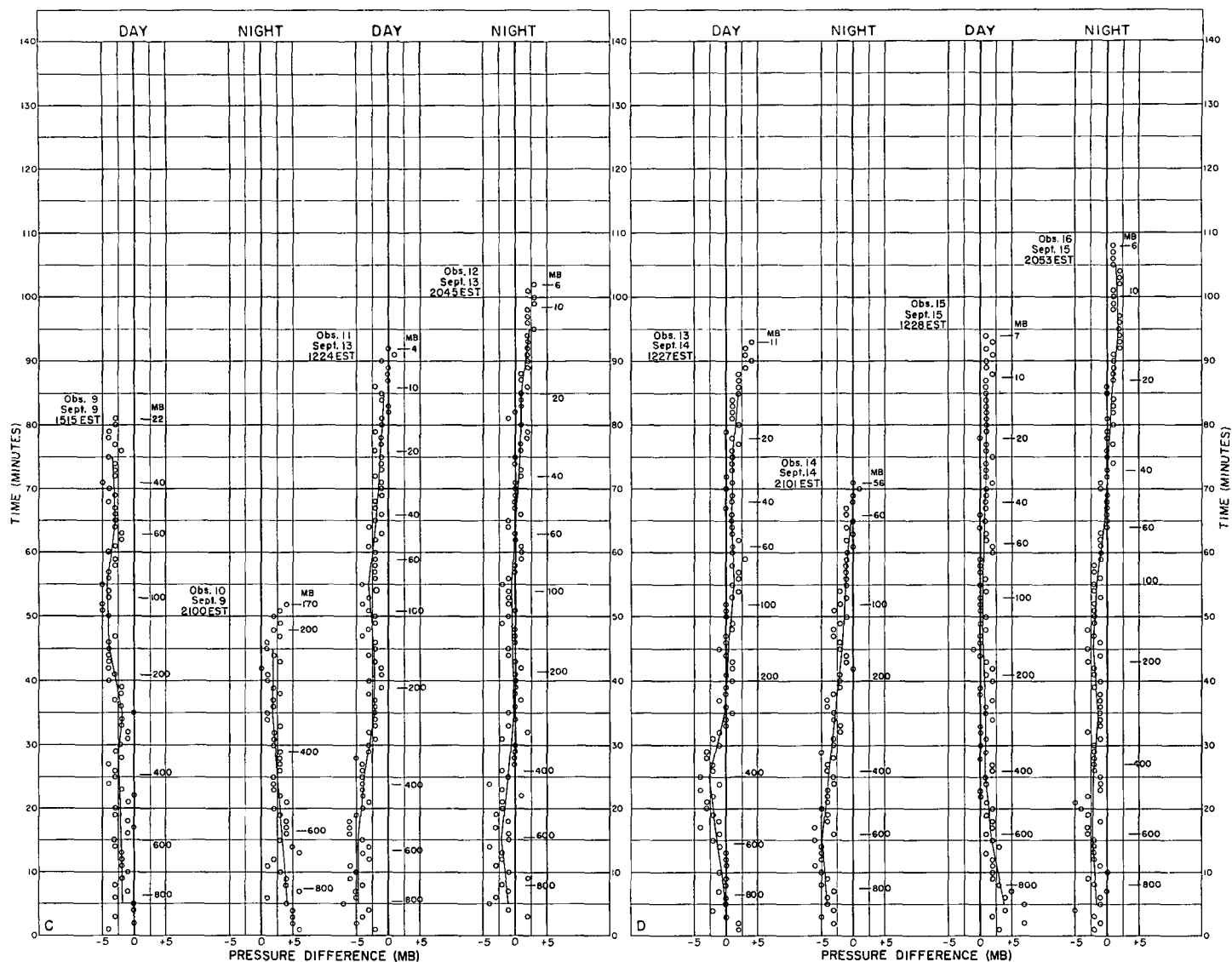
FIGURE 4.—Continued.

realistic picture possible, the observations were evaluated using significant level techniques in accordance with field procedures as described in [4]. Differences between radiosondes reported from this second type of evaluation represent those that one may expect at field stations manned by competent observers.

In routine operation it is not practical to evaluate excessively large numbers of levels. To eliminate levels of least importance, tolerances have been established in evaluation procedures ([4], par. 3214) which permit the exercise of judgement in selecting significant levels. This may cause an unavoidable degradation of accuracy in reported radiosonde data.

The temperature differences and average differences between pairs of radiosondes, read from the adiabatic charts at constant pressure levels, are shown for daytime observations in table 2a and for nighttime observations in table 2b. The average daytime difference at all levels is 0.19°C., and the average nighttime difference is 0.36°C.,
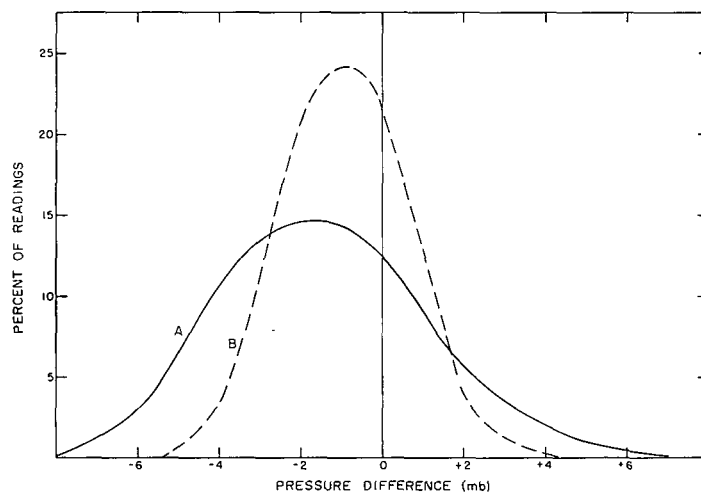

FIGURE 5.—Averaged distribution curves of pressure differences at simultaneous times: (A) surface to 400 mb.; (B) pressures less than 400 mb.

TABLE 2.—*Daytime (a) and nighttime (b) temperature differences in °C. between pairs of radiosondes at constant pressure levels obtained from the adiabatic charts.* (— *indicates temperature of Weather Bureau radiosonde lower than that of military radiosonde.*)

Pressure (mb.)	(a) Day Observation No.									Pressure (mb.)	(b) Night Observation No.								
	1	3	5	7	9	11	13	15	Average		2	4	6	8	10	12	14	16	Average
1000	0.0	-0.1	-0.2	0.7	0.0		0.0	-0.8	-0.1	1000	-0.1	-0.2	-0.5	0.0	0.1	0.0	-0.2	0.0	-0.1
850	-.1	-.3	-.4	-.9	-.6	-0.6	0.0	.4	-.3	850	.3	.4	-.2	-.4	-.8	-.5	.1	.2	-.1
700	-.8	-1.3	.4	.2	-.2	.8	-.3	-.6	-.2	700	.3	.6	-.6	0.0	-.3	-.6	-1.0	0.0	-.1
500	-.3	-.6	.4	-.9	-.7	.2	.2	0.0	-.2	500	.8	-.2	-.5	.4	-1.0	-.1	.6	.1	0.0
400	.3	0.0	.5	.1	0.0	.2	-.1	-.3	.1	400	1.0	.6	-.1	1.0	-1.1	.2	.7	.6	.4
300	1.9	.8	.9	.4	.6	-.1	.3	-.1	.6	300	1.3	.7	-.1	.2	-.4	.7	.4	1.2	.5
250	1.1	.9	0.0	1.2	1.1	.1	.3	.1	.6	250	.9	.5	0.0	1.0	-.6	0.0	.6	.3	.3
200	.3	.2	1.2	.8	1.0	1.9	-.5	-.2	.6	200	1.0	1.1	.1	.6	-.8	-.3	1.7	.7	.5
150	.3	.7	1.3	.7	2.0	1.2	.4	1.1	1.0	150	.6	.4	.4	.8		.4	-.3	1.0	.5
100	.5	1.7	-.8	1.2	.1	-.2	-.1	.9	.4	100	1.1	1.2	.9	-.1		.2	-.2	.5	.5
70	.8	-.9	0.0	-.2	-.9	1.1	1.6	-.4	.1	70	-.1	.2	.3	.4		.2	.5	.6	.3
50	-.6	-.9	.7	.3	.2	-.7	.6	.1	0.0	50	.6	.1	1.0	.9		2.0		.9	.9
30	.9	-.4	.9		-1.2	.6	.2	.7	.2	30		.4	.6	1.0		-.3		-.5	.2
20		-1.6	.1			-.1	.2	-.2	-.3	20		-.3	-.8	1.4		.9		.9	.3
10						-.1	1.5	.1		10						1.7		.2	
7						-2.5		1.5		7						3.5		3.1	

with the Weather Bureau radiosonde indicating higher values than the military. In the region 400 to 20 mb., these averages become 0.36°C., by day and 0.47°C. by night. Also a very small negative temperature difference in the lower levels progresses to a small positive difference (i.e., Weather Bureau temperature higher) in the upper levels, with a maximum near the tropopause. The difference remains constant or decreases as the temperature increases above the tropopause. This suggests a small factory calibration difference between the radiosondes which is verified by laboratory tests and will be described in the next section.

Considering all temperature differences at the mandatory pressure levels, 53 percent of the differences by day and 52 percent by night were within ±0.5°C.; 82 percent by day and 89 percent by night within ±1.0°C.; and 99 percent by day and 98 percent by night within ±2.0°C. A comparison of these values with the average differences from the simultaneous evaluations of the previous section shows the small degradation of the data contributed by the evaluation tolerances.

Though the effect of evaluation tolerances in selection of significant levels is usually small, in a few cases it is outstanding. This is seen when large or abrupt temperature differences in tables 2 (a) and (b) are compared with the simultaneous differences shown in figure 1. For example, in observation No. 1, table 2(a), 1.9° C. and 1.1° C. temperature differences at 300 and 250 mb., respectively, seem unexpectedly large as compared with differences at other levels. Examination of figure 1(A) shows the maximum simultaneous temperature difference is 0.6° C. between 400 and 200 mb.; figure 4(A) shows the maximum pressure difference is 3 mb. Thus a large part of the 1.9° C. difference must be assigned to selection of levels. The addition of one level on one record would have reduced these differences to 0.8° C. and 0.7° C., respectively.

All differences in excess of 2.0° C. occurred at the 7-mb. pressure level. At this level the temperature differences seem large and out of line with differences at the lower levels of the same observations. Furthermore, these large differences are not shown in the simultaneous differences in figure 1(C) and (D). These large and unrepresenta-

TABLE 3.—*Daytime (a) and nighttime (b) height differences in geopotential meters between pairs of radiosondes at constant pressure levels obtained from the adiabatic charts.* (— *indicates heights obtained by Weather Bureau radiosonde are lower than those by military radiosonde.*)

| Pressure (mb.)	(a) Day Observation No.									Pressure (mb.)	(b) Night Observation No.								
	1	3	5	7	9	11	13	15	Average		2	4	6	8	10	12	14	16	Average
1000	0	0	0	0	0		-3	3	0.0	1000	0	0	0	-1	0	0	0	0	-0.1
850	0	0	-3	1	1	-1	-5	2	-0.6	850	-4	3	-7	3	-3	-4	4	1	-.9
700	2	-3	-3	0	0	0	-10	-1	-1.9	700	-4	5	-10	5	-4	-8	-3	1	-2.3
500	0	-10	-3	-2	-3	-1	-10	-3	-4.0	500	0	4	-17	11	3	-12	-6	2	-1.9
400	2	-11	-2	-5	-1	0	-8	-5	-6.8	400	8	6	-21	15	-10	-10	-2	6	-1.0
300	13	-11	5	-3	2	1	-4	-5	-2.5	300	19	9	-21	22	-10	-8	6	16	4.1
250	21	-5	8	-1	6	0	-1	-4	3.0	250	24	12	-20	25	-11	-8	7	21	6.3
200	28	-2	14	6	12	0	1	-6	6.6	200	32	18	-19	30	-15	-5	16	23	10.0
150	33	0	25	10	23	7	1	-3	12.0	150	37	20	-22	36		-5	23	28	16.7
100	39	2	29	19	18	14	3	-3	15.1	100	48	26	-17	44		1	26	39	23.9
70	70	0	40	30	0	14	20	10	23.0	70	30	0	-10	50		20	40	40	24.3
50	57	-1	35	23	-4	2	13	-2	15.4	50	50	37	6	65		11		42	35.2
30	63	-7	56		-15	10	15	5	18.1	30		43	20	81		11		41	39.2
20		-16	61			13	12	13	16.6	20		41	17	94		18		48	43.5
10						12	46	5		10						46		62	
7						10		26		7						80		90	
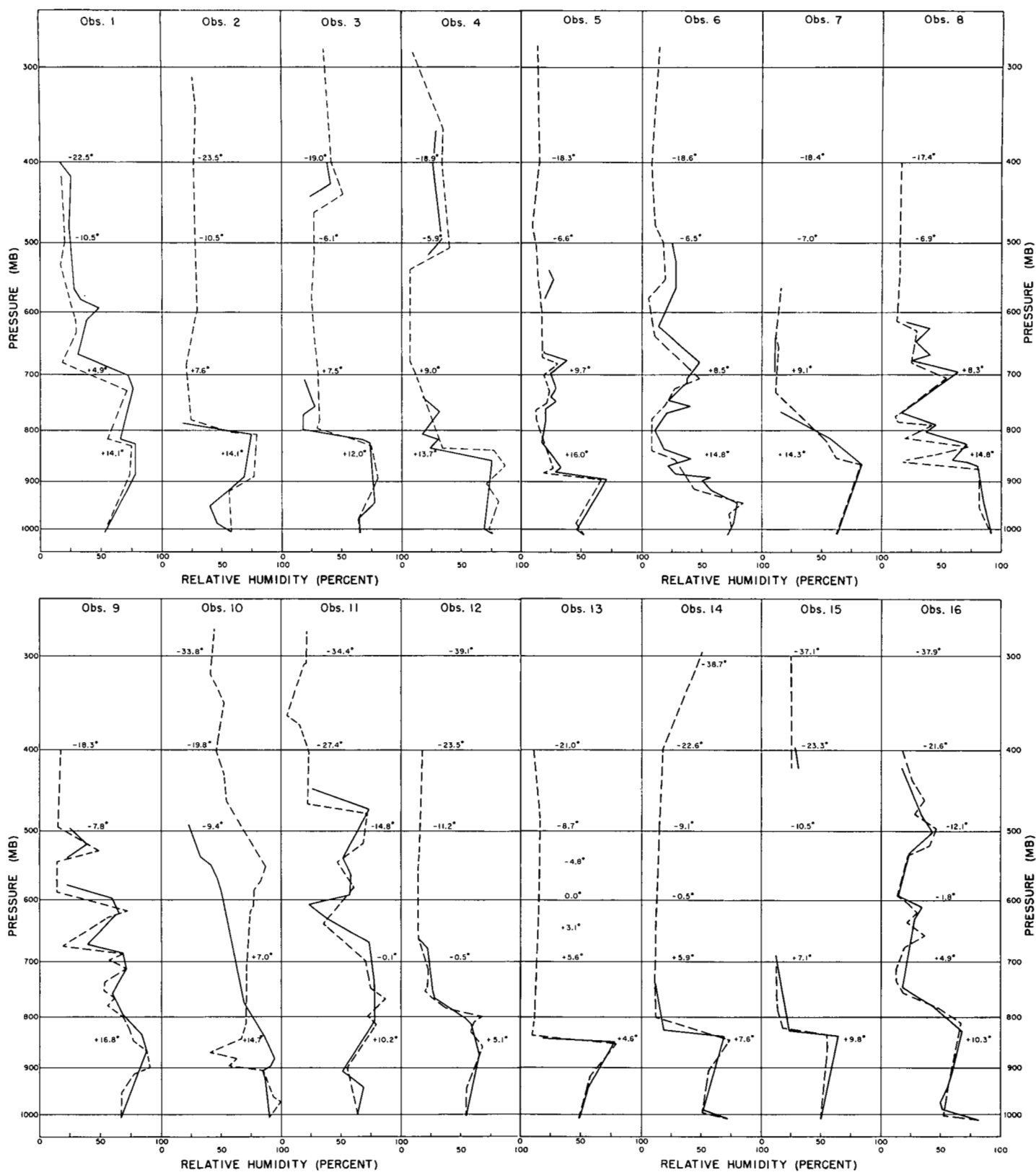
FIGURE 6.—Relative humidity values of radiosonde pairs, Weather Bureau (lithium chloride, solid lines) and military (carbon, dashed lines), plotted at significant levels.

tive temperature differences are caused by pressure differences between the radiosondes for these top levels. To illustrate, on observation No. 12 the last usable level for the military radiosonde was near 102 min. and was evaluated as −45.0° C., 6 mb.; for the Weather Bureau radiosonde the last level was at 107 min. and was evaluated as −40.9° C., 6 mb. The actual temperature difference at 102 min. was 0.4° C., but the pressure difference was 3 mb. The 3-mb. pressure difference caused an apparent 4.1° C. temperature difference at the plotted pressure of 6 mb.

Tables 3(a) and 3(b) show height differences in geopotential meters, by day and by night, at constant pressure levels as read from the adiabatic charts. By night the average height differences increase with height throughout the soundings and by an amount equivalent to that expected from the average temperature differences. By day the height differences above the 70-mb. level decrease. This anomalous behavior was not investigated but is ascribed to the combination of radiosonde errors and evaluation tolerances resulting from a small number of observations. However, the performance of the radiosondes is best shown in the previous section where simultaneous data are compared.

A comparable analysis was not made for relative humidity measurements because the sensors could not be examined in advance of the observations. Furthermore the sensors were used from stocks which were not identified from their factory "type" tests. Accordingly the relative humidity values, obtained from synoptic-level evaluations, are plotted for each observation in figure 6 without comment, other than to note certain characteristics of the two sensors. The lithium chloride element washes off in rain and records too low after drying, while the carbon element records too low in the wet state and resumes correct recordings after drying. Observation 10 is an illustration of this. At about 870 mb., we cannot tell if the decrease represents a dryer layer of air or a wet carbon element. One other observation is that despite the great difference in the speeds of response when the elements are tested in the laboratory there is very little confirmation of this in these soundings. (This may be of little interest since, in the near future, the carbon element will be used on all United States radiosondes.)

4. LABORATORY AND FACTORY TESTS

Mass production techniques are employed in radiosonde manufacture. Calibrations, in the true sense of the word, are not made except for the pressure element. With respect to temperature, it is only ascertained that the tolerance of ±0.5° C. is observed for the thermistor and also for the measuring circuit.

The radiosondes used in these twin observations were obtained at random from field stocks, except for the thermistors. These, too, were randomly selected but were calibrated at the factory prior to application of the white reflective coating. However, to obtain the maximum
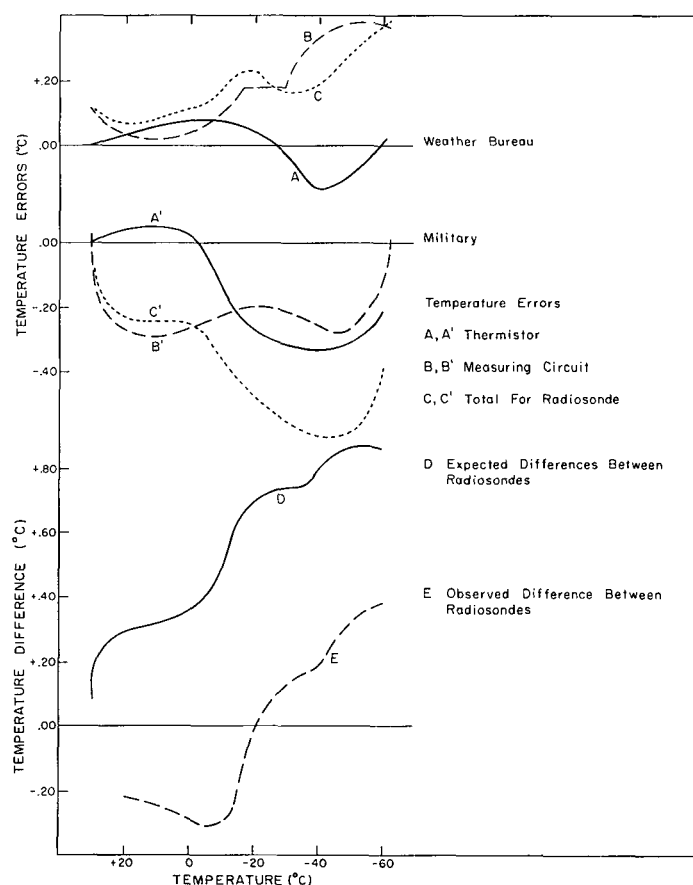

FIGURE 7.—Average temperature errors (curve C and C') of the two groups of radiosondes determined from factory and laboratory calibrations, average temperature differences between them (curve D) expected on the basis of these calibration errors, and the observed temperature differences (curve E). Curve A gives the average error of Weather Bureau thermistors, curve A' of military thermistors. Curve B gives the average error of the Weather Bureau radiosonde measuring circuit, and curve B' of the military circuits.

TABLE 4.—Temperature errors and averages (°C.) of thermistors which were used in these observations. Positive value indicates evaluated temperature higher than true. Errors at 30° C. are zero because of the lock-in procedure.

Observation No.	Weather Bureau radiosonde Test temperature (° C.)				Military radiosonde Test temperature (° C.)			
	0	−23.5	−40.0	−58.5	0	−20.0	−40.0	−58.5
1	0.00	−0.02	−0.11	0.00	−0.04	−0.27	−0.38	−0.14
2	.02	−.03	−.15	−.02	.07	−.22	−.40	−.13
3	−.02	−.12	−.27	−.19	−.07	−.30	−.48	−.38
4	.03	.02	−.21	−.08	−.01	−.31	−.42	−.23
5	.14	.06	−.13	.03	−.01	−.30	−.40	.20
6	.10	.58	−.11	.03	.04	−.25	−.25	−.29
7	.08	.10	−.10	−.02	.14	−.30	−.22	−.39
8	.12	.04	−.11	.03	.10	−.30	−.45	−.32
9	.05	.04	.00	−.15	−.06	−.25	−.42	−.17
10	.25	.23	.12	.27	.01	−.25	−.38	−.31
11	.05	−.12	−.22	−.11	.13	−.27	−.32	−.37
12	.12	.09	−.02	.18	.03	−.19	−.28	−.17
13	.03	.11	−.28	−.13	−.01	−.26	−.28	−.27
14	.15	.04	−.04	.06	.10	−.21	−.22	−.24
15	−.05	−.27	−.40	−.34	.13	−.29	−.18	−.25
16	.00	−.22	−.29	−.18	−.07	−.30	−.42	−.46
Average errors	.07	.03	−.14	−.04	.03	−.27	−.34	−.24

information from analysis of the data, particularly from the analysis of differences, the departure of the components from their calibrations and standard curves should be known. This required factory and laboratory calibrations of the components for pressure and temperature. These radiosondes were examined and calibrations were made. This action did not change them from their original condition nor did it affect their flight performance. The calibration data were not used in any of the evaluations of the flight comparisons. The results are presented in this section for a better understanding of the differences found in the previous sections, and further for additional information on accuracies which may be expected from field radiosondes.

Experience has shown that the temperature error of radiosondes is approximated by the algebraic sum of two error curves; one, the temperature error of the thermistor as a function of temperature, the other, the temperature error of the radiosonde measuring circuit (often spoken of as the modulator) as determined on the ground equipment.

Thermistors were calibrated at the factory before application of the reflective coating rather than in the Weather Bureau laboratory to avoid possible injury to the white coating. The temperature error of the radiosonde measuring circuit was determined in the Weather Bureau laboratory. Table 4 shows the thermistor temperature errors at the calibration temperatures and table 5 shows the temperature errors of the measuring circuit under two test voltage conditions. The average errors of tables 4 and 5 are shown in figure 7.

Curves A and B (fig. 7) represent the average temperature errors of the Weather Bureau thermistors and of the radiosonde measuring circuit, respectively. Curve C is the average temperature error of the group of radiosondes resulting from the algebraic sum of the two errors. Curves A', B', and C' represent similar errors for the military group of radiosondes. Curve D shows the difference in temperature between the two groups which would be expected on the basis of the combined error curves C–C', and curve E shows the observed difference.

If no other errors of temperature measurement were considered, the two radiosonde groups represented here would be expected to give the differences shown in curve D. This gives no indication of radiosonde accuracy, only of relative temperature difference. Curves C and C' are an indication of average group accuracy of the radiosondes. Examination of tables 4 and 5 shows individual variations

TABLE 5.—*Temperature errors and averages (° C.) of radiosonde measuring circuits at two A and B voltages and over a temperature range 27° C. to −63° C. Positive sign indicates evaluated temperature higher than true*

	Weather Bureau radiosonde												
Observation No.	Test volts 6.0, 110						Test volts 5.5, 90					
	Test temperature (° C.)						Test temperature (° C.)					
	27.1	15.3	0.0	−17.5	−30.1	−44.7	−63.1	27.1	15.3	0.0	−17.5	−30.1	−44.7	−63.1
1	0.0	−0.2	−0.1	0.0	0.1	−0.2	−0.4	0.0	−0.2	−0.1	0.0	0.2	−0.2	−0.4
2	0.0	−0.2	−0.1	0.0	0.0	0.3	0.4	−0.2	−0.2	−0.1	0.0	0.0	0.3	0.4
3	0.0	−0.1	0.1	0.1	0.2	0.4	0.5	0.0	−0.1	0.1	0.2	0.2	0.4	0.5
4	0.0	0.1	0.2	0.3	0.2	0.4	0.5	0.3	0.3	0.4	0.3	0.3	0.6	0.5
5	0.0	−0.2	−0.1	0.0	0.1	0.2	0.3	0.0	−0.2	−0.1	0.0	0.1	0.2	0.3
6	0.0	0.0	−0.3	0.0	0.1	0.3	0.4	0.0	0.0	−0.1	0.1	0.2	0.3	0.4
7	0.0	−0.2	0.0	0.1	0.1	0.4	0.7	0.3	0.2	0.1	0.2	0.3	0.5	0.7
8	0.0	0.1	0.1	0.3	0.2	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.6	0.5
9	0.0	−0.1	−0.1	0.1	0.0	0.3	0.2	0.3	0.3	0.2	0.3	0.3	0.4	0.5
10	0.0	0.1	0.1	0.2	0.1	0.4	0.2	0.0	0.1	0.1	0.3	0.2	0.4	0.5
11	0.0	−0.1	−0.2	0.1	0.0	0.3	0.3	0.0	−0.1	−0.2	0.1	0.0	0.3	0.3
12	0.0	−0.1	0.0	0.1	0.0	0.3	0.3	0.2	0.1	0.1	0.3	0.2	0.4	0.2
13	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.0	0.0	−0.2	0.0	0.1	0.3	0.4
14	0.0	0.0	0.1	0.1	0.1	0.3	0.4	0.3	0.2	0.1	0.3	0.2	0.3	0.6
15	0.0	0.1	0.1	0.2	0.2	0.4	0.2	0.5	0.3	0.2	0.4	0.3	0.6	0.2
16	0.0	0.1	0.1	0.4	0.3	0.6	0.5	0.2	0.1	0.1	0.4	0.5	0.6	0.5
Average	0.0	−0.4	−0.1	0.13	0.11	0.32	0.34	0.15	0.08	0.06	0.22	0.23	0.38	0.38

	Military radiosonde												
Observation No.	29.9	7.6	−8.6	−22.4	−33.4	−45.8	−61.3	29.9	7.6	−8.6	−22.4	−33.4	−45.8	−61.3
1	0.0	−0.2	−0.3	−0.2	−0.2	−0.1	0.2	0.0	−0.2	−0.3	−0.2	−0.2	−0.3	−0.1
2	0.0	−0.4	−0.3	−0.2	−0.2	−0.1	0.2	0.0	−0.2	−0.3	−0.2	−0.2	−0.3	0.2
3	0.0	−0.2	−0.3	−0.2	−0.2	−0.1	0.2	0.2	−0.2	−0.3	−0.2	−0.2	−0.3	0.2
4	0.0	−0.4	−0.4	−0.2	−0.2	−0.3	0.2	0.2	−0.1	−0.1	−0.1	0.0	−0.1	0.2
5	0.0	−0.4	−0.4	−0.3	−0.3	−0.3	0.2	0.0	−0.4	−0.4	−0.3	−0.3	−0.3	0.2
6	0.0	−0.3	−0.3	−0.2	−0.2	−0.3	0.1	0.0	−0.3	−0.2	−0.1	−0.2	−0.3	0.3
7	0.0	−0.2	−0.1	−0.1	0.0	−0.3	0.2	0.0	−0.2	−0.1	−0.1	−0.2	−0.1	0.2
8	0.0	−0.2	−0.2	−0.1	−0.1	−0.3	0.1	0.0	−0.2	−0.2	−0.1	−0.3	−0.1	0.1
9	0.0	−0.3	−0.2	−0.3	−0.1	−0.3	0.1	0.2	−0.1	−0.1	−0.1	0.0	−0.1	0.1
10	0.0	−0.5	−0.4	−0.2	−0.3	−0.6	−0.5	0.0	−0.5	−0.4	−0.2	−0.3	−0.6	−0.5
11	0.0	0.3	0.1	0.1	0.0	−0.2	−0.3	0.4	0.1	0.1	0.1	0.0	−0.2	−0.3
12	0.0	−0.5	−0.3	−0.4	−0.3	−0.4	−0.3	0.0	−0.5	−0.3	−0.4	−0.2	−0.4	−0.3
13	0.0	−0.3	−0.3	−0.3	−0.3	−0.5	0.0	−0.2	−0.6	−0.5	−0.4	−0.4	−0.5	0.0
14	0.0	−0.3	−0.2	−0.1	−0.2	−0.3	0.1	0.0	−0.3	−0.3	−0.2	−0.2	−0.3	0.1
15	0.0	−0.4	−0.4	−0.3	−0.3	−0.4	−0.1	0.0	−0.4	−0.4	−0.3	−0.3	−0.4	−0.1
16	0.0	−0.5	−0.3	−0.2	−0.3	−0.4	−0.3	0.0	−0.5	−0.3	−0.2	−0.3	−0.3	−0.3
Average	0.00	−0.30	−0.27	−0.20	−0.20	−0.31	0.01	0.05	−0.29	−0.26	−0.19	−0.21	−0.30	0.00

TABLE 6.—*Pressure errors (mb.) of the laboratory recalibration at room temperature, approximately 25° C. (radiosonde indicated minus true)*

Pressure (mb.)	Weather Bureau radiosonde — Observation No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1000	−1.0	2.5	3.0	−1.0	0.0	1.5	−1.0	−0.5	−0.5	0.5	1.0	0.0	2.5	0.0	0.0	−0.5
900	−1.0	2.0	0.0	−1.5	2.0	2.0	3.0	0.0	0.0	1.5	3.0	1.0	3.0	−1.0	.5	−.5
800	.5	1.5	0.0	0.0	1.5	1.5	2.5	−2.0	.5	1.5	.5	1.0	1.0	−1.0	1.5	−1.0
700	−1.0	2.0	.5	0.0	1.5	2.0	3.0	−1.0	−.5	2.0	1.5	1.0	0.0	−1.0	1.0	−1.0
600	−1.5	1.0	2.0	0.0	1.0	2.0	3.0	0.0	0.0	2.0	2.0	1.0	0.0	−.5	2.0	−1.0
500	0.0	1.0	.5	−1.0	.5	1.0	3.0	−.5	−1.0	2.0	0.0	.5	−1.0	−1.0	1.0	−1.0
400	−1.5	1.0	1.0	−.5	1.0	1.5	2.0	0.0	−1.0	.5	1.0	0.0	−.5	−1.5	2.0	−.5
300	−1.0	1.5	1.0	0.0	.5	1.0	2.5	0.0	−1.0	.5	1.0	0.0	−1.0	−1.5	1.0	−.5
200	0.0	1.5	−.5	0.0	−.5	.5	1.5	0.0	−1.0	.5	1.0	−.5	−.5	−1.5	.5	−.5
100	0.0	2.0	.5	.5	−.5	.5	1.5	−.5	−1.0	.5	0.0	.5	1.0	−1.5	1.0	0.0
80	0.0	1.5	0.0	0.0	−.5	1.0	1.0	−.5	−2.0	0.0	1.0	1.0	.5	−1.0	1.0	0.0
60	−1.0	1.5	0.0	1.0	0.0	.5	1.0	0.0	−1.5	1.0	1.0	.5	0.0	−1.0	.5	.5
40	−.5	1.0	0.0	0.0	−.5	1.0	1.0	0.0	−.5	1.0	1.0	0.0	1.0	−1.0	1.5	.5
20	−.5	1.0	.5	.5	−.5	1.0	1.5	0.0	−1.0	.5	1.0	.5	0.0	−1.0	1.5	.5
	Military radiosonde															
1000	1.0	−1.0	−0.5	0.0	−3.0	−3.0	−3.0	1.0	0.5	−2.5	0.0	0.0	−3.5	1.0	−0.5	−2.5
900	3.0	1.0	0.0	.5	−1.5	−.5	−2.0	0.0	2.0	−1.5	0.0	0.0	0.0	0.0	0.0	−1.0
800	5.0	1.5	1.5	1.0	−2.0	.5	0.0	1.0	3.5	0.0	2.5	2.0	0.0	2.0	2.0	−1.0
700	4.5	.5	1.5	1.0	−1.0	.5	0.0	1.0	2.0	−1.0	1.0	2.0	0.0	2.5	3.0	0.0
600	6.0	1.0	3.0	1.5	−1.5	0.0	1.0	1.0	3.0	−1.0	2.5	1.5	1.0	2.5	2.5	0.0
500	2.0	−1.0	1.0	2.0	−.5	−.5	0.0	1.5	2.0	−1.0	2.5	2.0	0.0	2.0	2.0	0.0
400	2.0	0.0	2.0	2.0	−.5	.5	.5	.5	2.0	−2.5	1.5	1.0	−1.0	1.5	1.0	−1.0
300	2.0	0.0	2.0	1.5	−1.0	0.0	−.5	1.0	1.5	−1.0	1.0	.5	−.5	2.0	1.0	0.0
200	3.0	.5	2.0	2.5	−1.0	.5	−1.0	.5	3.0	−2.0	.5	0.0	−1.0	1.5	1.0	0.0
100	2.0	.5	1.5	3.5	−.5	−.5	.5	1.5	4.0	−1.5	1.0	0.0	0.0	1.0	0.0	−.5
80	1.5	1.0	2.0	2.5	−1.0	.5	0.0	.5	2.5	−2.0	.5	−.5	0.0	1.0	1.0	−1.0
60	.5	.5	.5	1.0	−.5	0.0	0.0	.5	3.0	−2.5	0.0	−.5	0.0	0.0	1.0	−1.0
40	1.0	1.0	1.5	0.0	−1.5	0.0	0.0	1.5	3.0	−3.0	.5	−.5	−1.0	0.0	.5	−.5
20	1.0	2.0	2.5	2.5	−2.0	−1.0	−1.0	1.5	4.0	−3.0	0.0	−1.0	−.5	0.0	0.0	−1.5

among these radiosondes. Because radiosonde specifications have a range of tolerances for temperature and pressure, other groups of radiosondes may show different trends depending upon manufacturers and dates of procurement.

In the actual radiosonde observation, temperature accuracy indicated by laboratory tests is further degraded by temperature errors introduced through the baseline check, i.e., the one-point temperature calibration made prior to release. In this temperature "lock in", errors may be introduced through errors in the thermometer or its reading, and through electrical "loading" effects or electrical "leakage" caused by moisture in the baseline check box. After release the temperature accuracy may be further degraded by electrical leakage if some vulnerable component gets wet, by evaporative cooling of water droplets from a wet thermistor, or by radiational cooling or heating, and by poor sensitivity in the ground equipment, particularly in the recorder.

That the accuracy of these observations was degraded somewhat by errors in the baseline check is shown by comparing curves D and E of figure 7. At +20° C. (just after release) the difference between the two curves is about 0.5° C. We ascribe this difference to the baseline checks whose errors are discussed above. Obviously, if the launching temperature checks had been perfect, this difference would have been zero. In general, the trend of the two curves is the same. That the observed differences are further displaced from those expected, we again ascribe to flight errors discussed above.

In radiosonde manufacture, pressure units (baro-

switches) are individually calibrated. Pressure accuracy depends upon the ability of the units to repeat this calibration under all field operating conditions. In the factory, quality control is maintained by repeat-pressure calibra-

TABLE 7.—*Differences in pressure (mb.) between cold and warm recalibration (80° C. below warm recalibration). Pressure cold test minus pressure warm test*

Pressure (mb.)	Weather Bureau radiosonde — Observation No.									
	1	2	3	4	5	6	7	9	14	16
1000	0.5	−3.0	−3.5	−1.5	−0.5	4.5	−3.5	−4.0	0.0	−0.5
900	−1.0	−3.0	−3.5	−3.0	1.0	4.0	−3.0	−4.0	0.0	−2.0
800	0.0	−3.5	−3.5	−1.0	.5	4.5	−3.0	−2.5	1.0	−1.5
700	0.0	−2.5	−2.5	−1.0	1.5	4.0	−2.0	−3.5	1.0	−2.0
600	0.0	−3.0	−1.0	−1.0	1.0	4.0	−2.0	−3.0	.5	−2.0
500	.5	−2.0	−2.0	0.0	1.0	3.0	−1.0	−3.0	1.0	−1.5
400	.5	−2.0	−1.0	−1.0	1.0	2.0	−2.0	−3.0	.5	−1.5
300	0.0	−1.5	−1.5	−1.0	.5	1.0	−2.5	−3.0	0.0	−1.0
200	2.0	−1.5	−2.0	−1.5	0.0	.5	−1.5	−3.0	−.5	−.5
100	1.0	−1.5	−1.0	−1.5	0.0	−.5	−2.0	−2.5	−.5	−.5
80	1.0	−2.0	−1.5	−1.5	.5	0.0	−2.0	−3.0	−1.0	−.5
60	1.0	−1.5	−1.5	−1.5	.5	0.0	−2.0	−2.5	−1.0	−.5
40	1.0	−2.0	−2.0	−2.0	.5	0.0	−2.0	−1.5	−1.5	−.5
20	.5	−2.0	−1.5	−1.5	.5	0.0	−1.5	−2.5	−1.0	−1.0
	Military radiosonde									
1000	4.5	4.0	0.5	2.5	−1.0	0.5	−3.0	2.0	0.5	-------
900	4.5	4.0	1.0	1.5	−1.0	0.0	−2.5	3.0	.5	-------
800	5.0	3.5	1.5	1.5	−2.0	.5	−1.5	4.0	1.5	-------
700	5.0	2.0	.5	1.5	−1.0	−.5	−1.5	2.5	2.0	-------
600	4.0	2.0	1.0	1.5	−2.5	−.5	−.5	3.0	1.0	-------
500	2.0	1.0	.5	1.0	−.5	0.0	−.5	2.0	0.0	-------
400	2.5	.5	.5	1.0	−.5	−.5	−.5	1.5	1.0	-------
300	2.0	0.0	0.0	.5	−.5	0.0	−1.0	1.5	1.0	-------
200	1.5	0.0	0.0	0.0	−.5	0.0	−2.0	1.0	.5	-------
100	0.0	−1.0	−1.0	.5	−.5	−.5	−1.0	.5	0.0	-------
80	.5	−1.0	0.0	0.0	−.5	−1.0	−1.0	0.0	0.0	-------
60	0.0	−1.0	−.5	0.0	0.0	0.0	−1.0	0.0	−.5	-------
40	0.0	−1.0	0.0	.5	−.5	−1.5	−1.0	.5	−.5	-------
20	−.5	−1.0	−.5	.5	−1.0	−.5	−1.0	1.0	−.5	-------

FIGURE 9.—Distribution of temperature errors (indicated minus true) from factory flight similitude tests on Weather Bureau radiosondes. Curve A, surface to 400 mb.; curve B, pressures less than 400 mb.
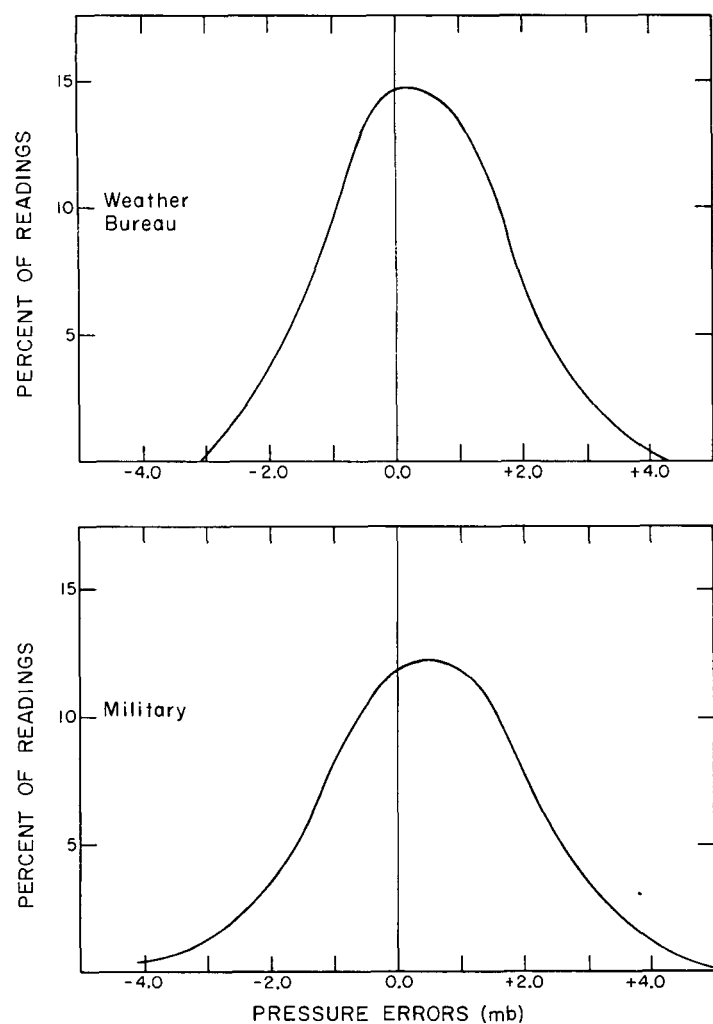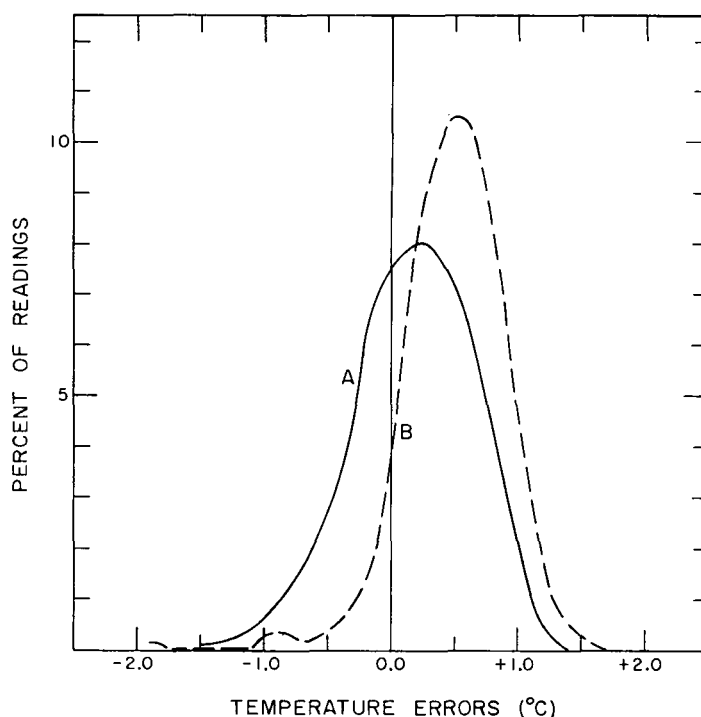

FIGURE 8.—Distribution curves of pressure errors obtained from laboratory recalibration of pressure units. (See table 6.)

tions at room temperature and again at a temperature 80° C. lower. These statistical sampling tests are performed as a continuing quality control process on radiosonde deliveries. All baroswitches used in these observations were given a room temperature recalibration in the Weather Bureau laboratory. Table 6 shows the pressure errors on this recalibration. The baroswitch was adjusted to ambient pressure by the detent mechanism at the beginning of this test so that detent or "setting" errors are included in table 6. Table 7 shows the differences between cold and warm calibration for those radiosondes that were cold tested.

The frequency distribution of the warm recalibration error is shown in figure 8. For the Weather Bureau group, only 5 percent of the errors exceeded ±2 mb.; for the military group, only 15 percent exceeded ±2 mb. As the majority of the military radiosondes were five years old when used, this "repeatability" is remarkably good. When larger statistical populations are used, the distribution error curve is very nearly normally distributed
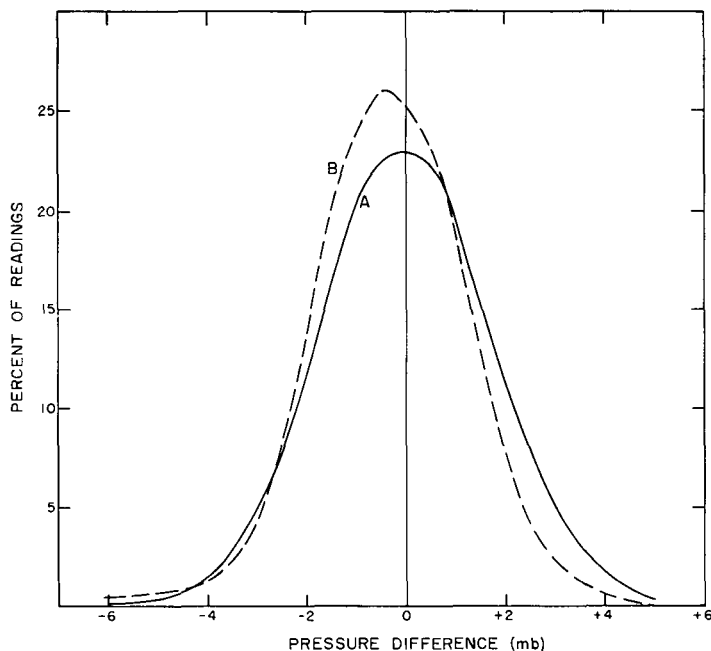

FIGURE 10.—Distribution of pressure errors (indicated minus true) from factory flight similitude tests on Weather Bureau radiosondes. Curve A, surface to 400 mb.; curve B, pressures less than 400 mb.

about zero. The small pressure differences between pairs of radiosondes (fig. 5) demonstrate that the errors obtained on the laboratory tests are representative of those to be expected during an observation, as one remembers that, for the group average, these baroswitches were within ±2 mb. of the original calibration 90 percent of the time. These distribution curves are typical of expectations from small groups of baroswitches.

The error of a radiosonde in temperature and pressure may best be determined in the laboratory by a flight similitude test. In such a test the radiosonde is prepared as for a flight, except for the humidity element, and is subjected to decreasing pressure and temperature; the rate of decrease equals that of a radiosonde ascending through the atmosphere at 1000 ft./min. True temperature and pressure are measured at frequent intervals and compared with the radiosonde indications. This test is time consuming and is performed on a small percentage of Weather Bureau radiosondes at the factory. It was not conducted on the radiosondes used in these tests; but factory data for other Weather Bureau radiosondes covering the production period of those used in this test are shown in figure 9 for temperature errors and figure 10 for pressure errors. In both cases curve A represents errors from surface pressure to 400 mb. inclusive, and curve B represents errors at all pressures less than 400 mb. This group of radiosondes indicated 0.2° to 0.5° C. higher than true temperature on the average; the largest positive errors occurred at the lowest temperatures, or at low pressures. These data are in agreement with the Weather Bureau data curve C of figure 7.

5. CONCLUSIONS

These data show that for the tested instruments differences between radiosondes used by the United States meteorological agencies are no greater than would be expected from procurements for different years and from different manufacturers by a single agency. The specification tolerances in temperature and pressure are similar and such a result would be expected. It should be pointed out again that the differences here reported give no indication of absolute accuracy of either of the two groups of radiosondes. It can be inferred from the laboratory data that both groups show approximately the same accuracy. The comparison at simultaneous times shows the differences to be expected between two radiosondes. On the average, this shows a root-mean-square difference of 2.1 mb. and 0.51° C., or an equivalent root-mean-square error per radiosonde of 1.5 mb. and 0.36° C.

The evaluation using established field procedures shows differences which would be expected in daily data reported as if there were no errors in evaluation or transmission.

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[*Received August 3, 1964; revised December 4, 1964*]